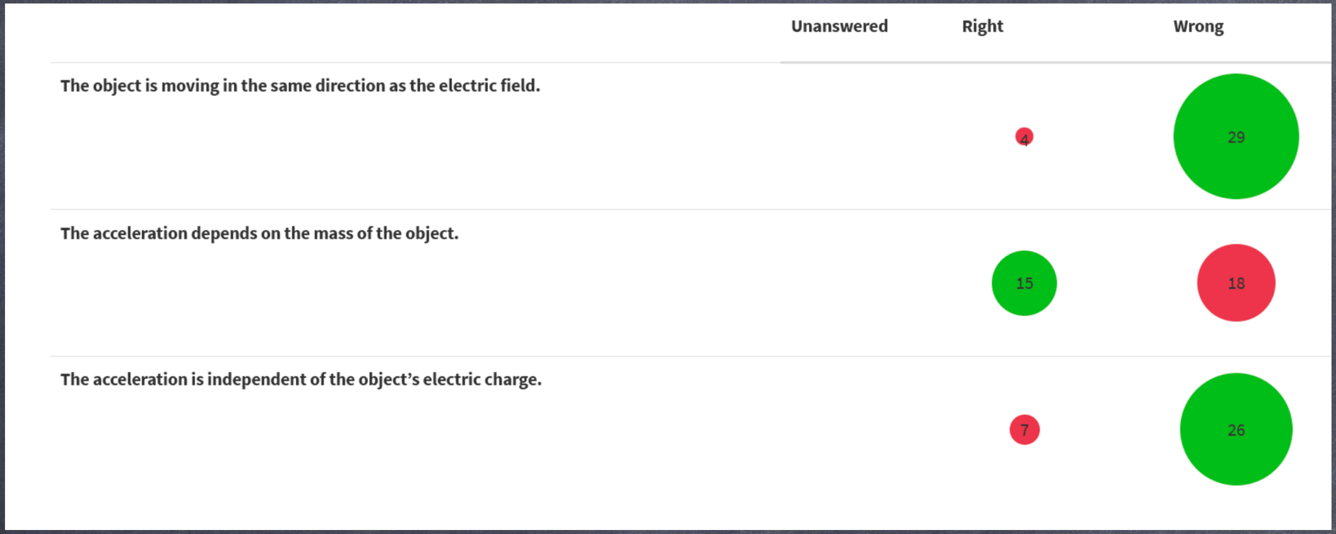
office hours 11:45-13:00 Fridays

PHY127

Prof. Ben Kilminster
Lecture 2
Mar. 3rd, 2023

Quiz questions:

A negatively charged object is accelerating with only an electric force. Which of the following are true ?



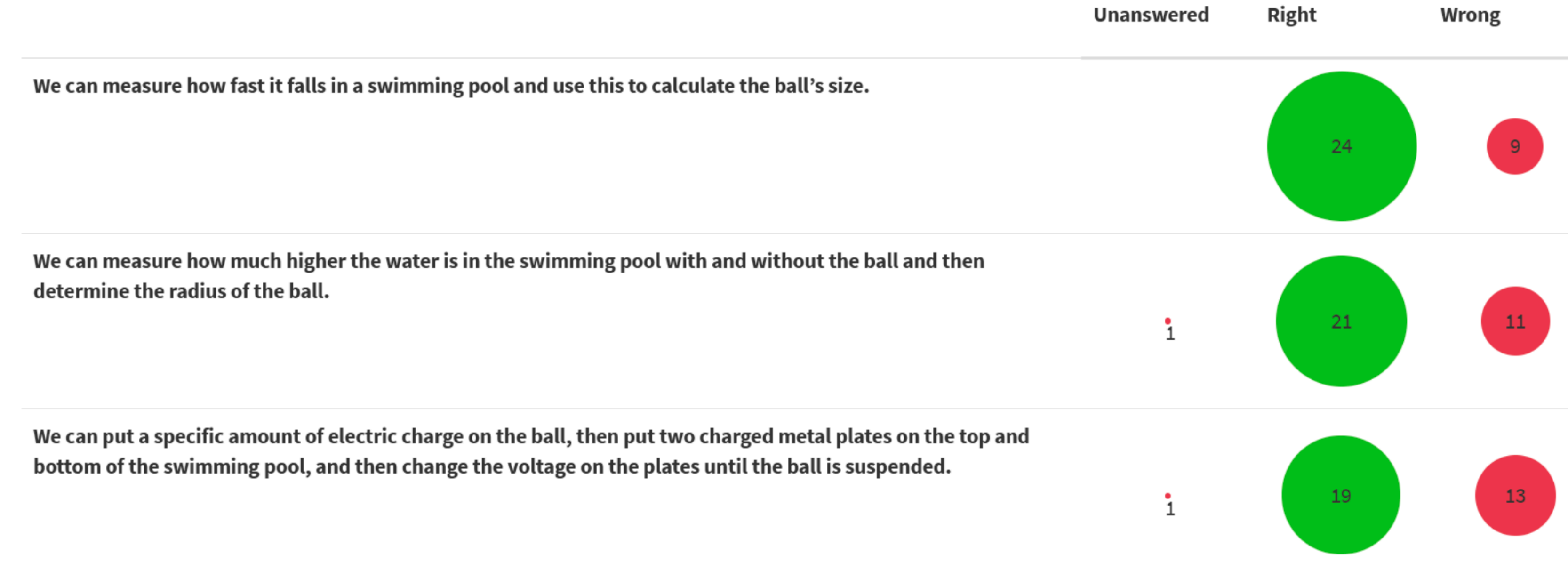
	Unanswered	Right	Wrong
The object is moving in the same direction as the electric field.		4	29
The acceleration depends on the mass of the object.		15	18
The acceleration is independent of the object's electric charge.		7	26

$$\Sigma F = ma$$

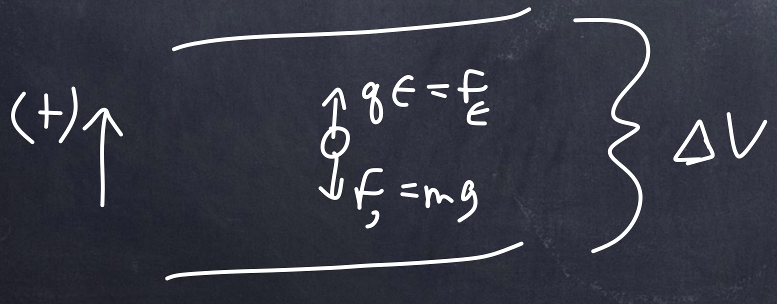
here $\Sigma F = qE = ma$

$$a = \frac{qE}{m} \leftarrow \text{depends on mass}$$

We want to precisely measure the radius of a very tiny ball of steel, but we don't have a ruler. We know the ball's density, but we can't measure its mass. We do have the internet and we have a swimming pool. How can we measure the radius ? (which are true?)



	Unanswered	Right	Wrong
We can measure how fast it falls in a swimming pool and use this to calculate the ball's size.		24	9
We can measure how much higher the water is in the swimming pool with and without the ball and then determine the radius of the ball.	1	21	11
We can put a specific amount of electric charge on the ball, then put two charged metal plates on the top and bottom of the swimming pool, and then change the voltage on the plates until the ball is suspended.	1	19	13



$E = \frac{\Delta V}{d}$

if suspended,

$\Sigma F = 0 = qE - mg$

$qE = mg$

$m = \frac{qE}{g} \rightarrow$ mass → volume → $V = \frac{4}{3}\pi r^3$

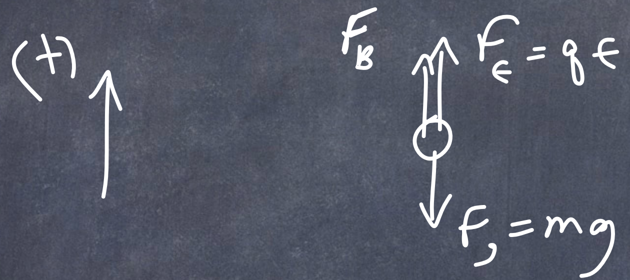
(we know density)

we know radius

Question in class: what about buoyant force?

Yes, there is a buoyant force because the ball will be pushed up by the weight of water it displaces.

If we account for this:



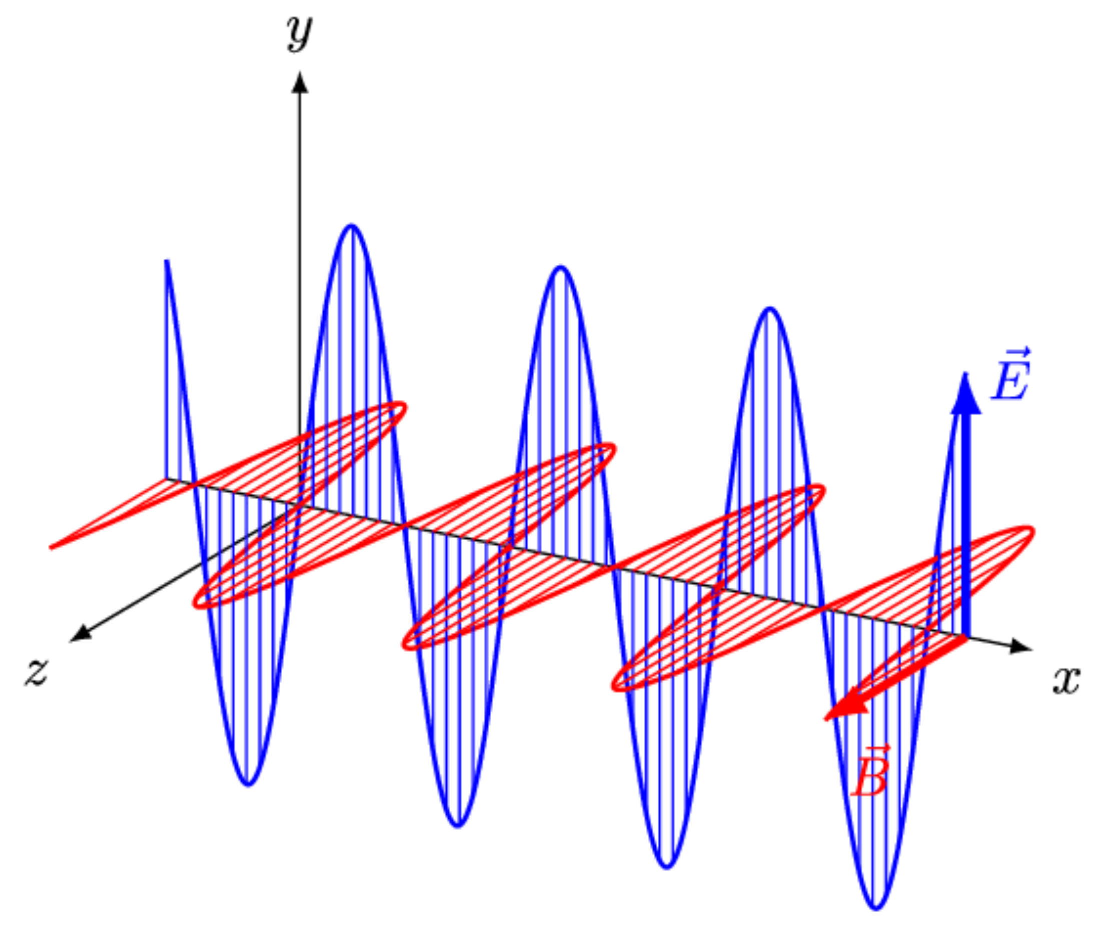
$F_B = \underset{\substack{\uparrow \\ \text{mass of} \\ \text{water}}}{m_w} g =$

if suspended, $\Sigma F = 0 = qE + m_w g - \underset{\substack{\uparrow \\ \text{mass of ball}}}{m_b} g$

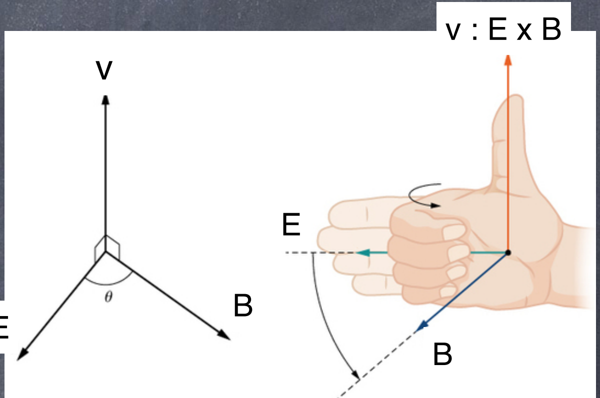
so $m_b = \dfrac{qE + m_w g}{g} = \dfrac{qE}{g} + m_w$

So we can get mass of ball → volume → radius

At end of PHY 117, you learned light is an electromagnetic wave. The amplitude of $\bar{E}$ is in $\hat{y}$-direction. The magnetic field is $\perp$ to $\bar{E}$ field, & is in $\hat{z}$-direction. The direction of propagation of light is $\bar{V} \sim \bar{E} \times \bar{B}$



$\bar{V}$ is in direction of $\hat{x}$-direction

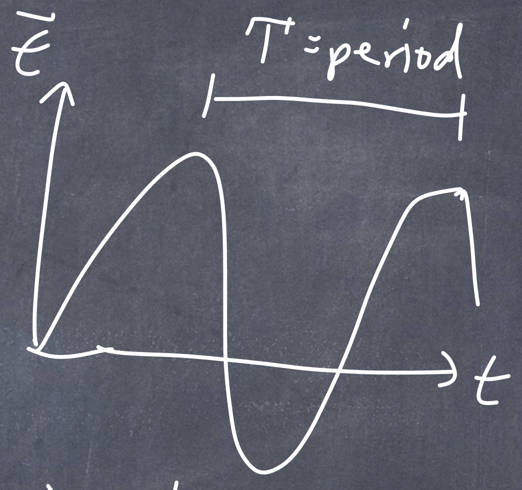


Review on cross products & unit vectors is in script physics I, Chapter 3.

Focussing on $\bar{E}$, it changes with position and time.

Light has a wavelength, λ,
units of [m]

and
has
a frequency,
ν $\left[\frac{1}{s}\right]$
Hz

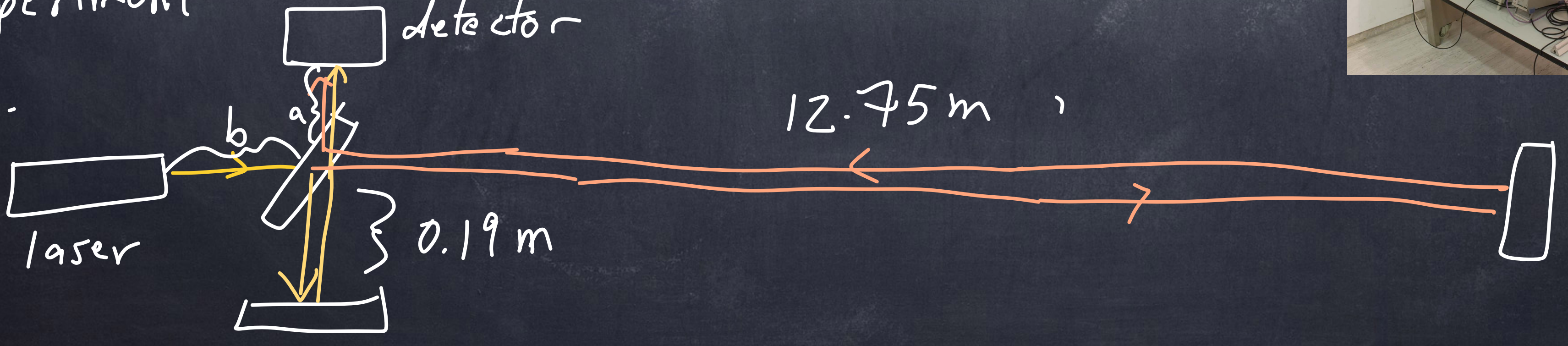


$\nu = \frac{1}{T}$

For a wave, $v = \lambda \nu$ $\left[\frac{m}{s}\right]$
velocity

For light,

Experiment



distance of path 1: $b + 2(12.75\,m) + a$
(longer)

distance of path 2: $b + 2(0.19\,m) + a$

$$\Delta x = \text{path 1} - \text{path 2} = \cancel{b} + \cancel{a} + 2(12.75m) - (\cancel{b} + \cancel{a} + 2(0.19m))$$

$$= 2(12.75m) - 2(0.19m) = 25.12\,m$$

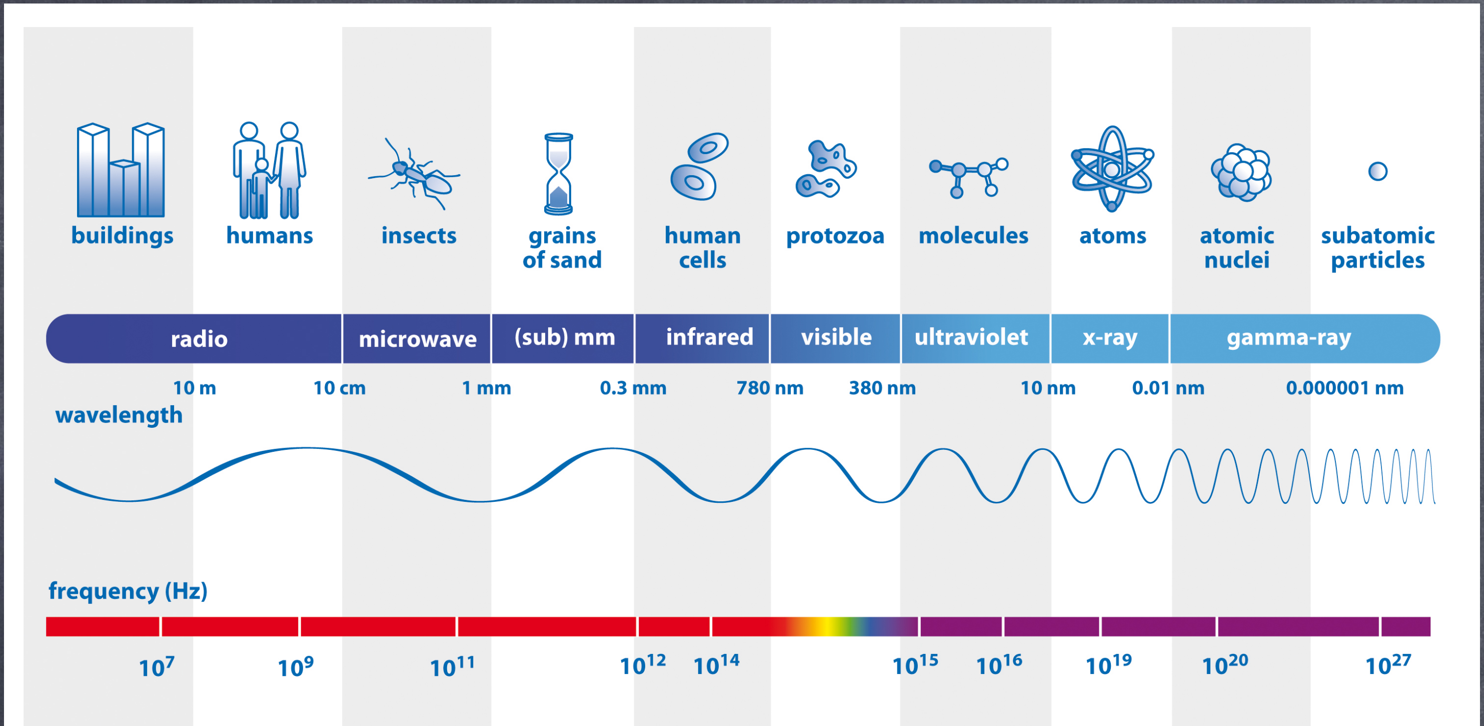
$$\Delta t = \text{measured} = 84\,E{-9}\,s$$

$$c = \frac{\Delta x}{\Delta t} = \frac{25.12m}{84\,E{-9}s} = 2.99\,E\,8\,\frac{m}{s}$$

$$\downarrow$$

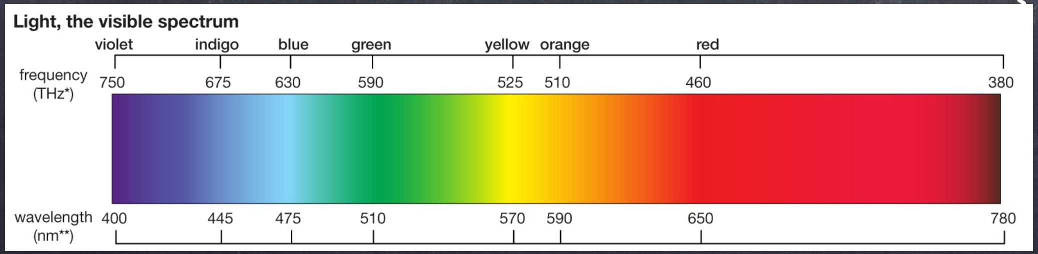
$$2.998\ldots\frac{m}{s}$$

Light can have many wavelengths & frequencies.



↓(flipped)

ultraviolet



infrared

↑ 400 nm

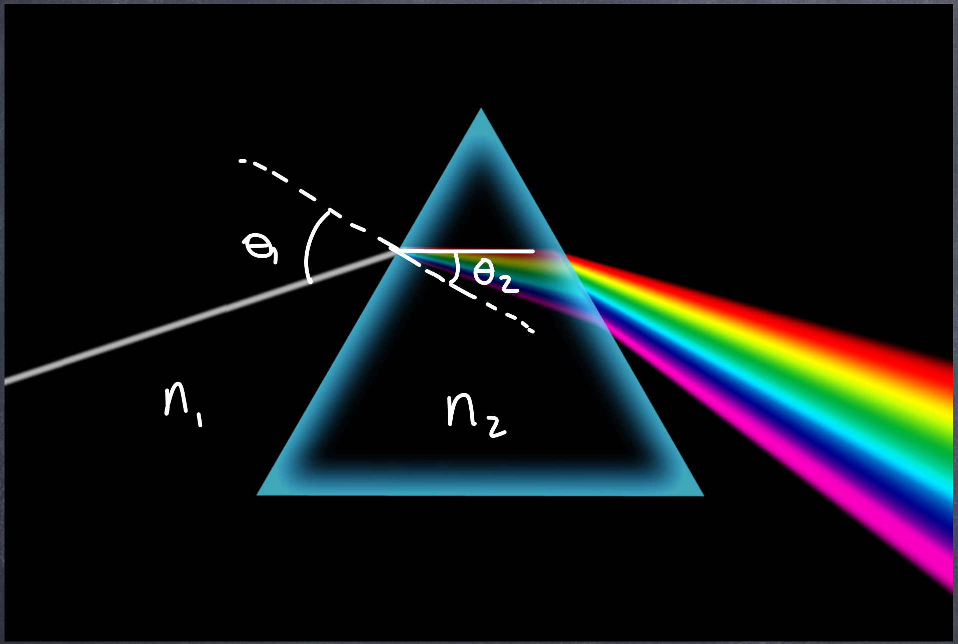
↑ 700nm

Experiment : split light

PHY 117:

Snell's Law : $\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$

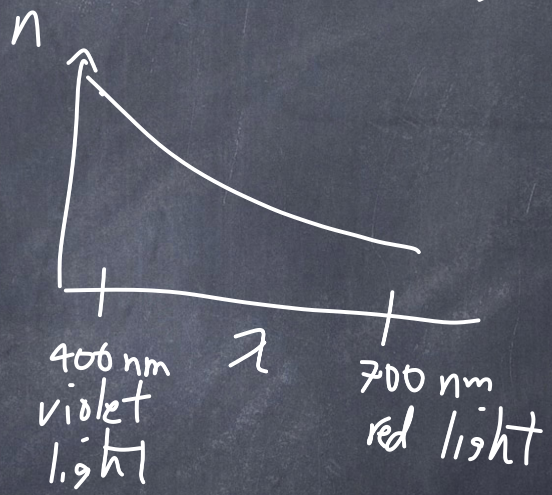
n : index of refraction



$n_1 \sim 1$ for air

$n_2 > n_1$ in glass

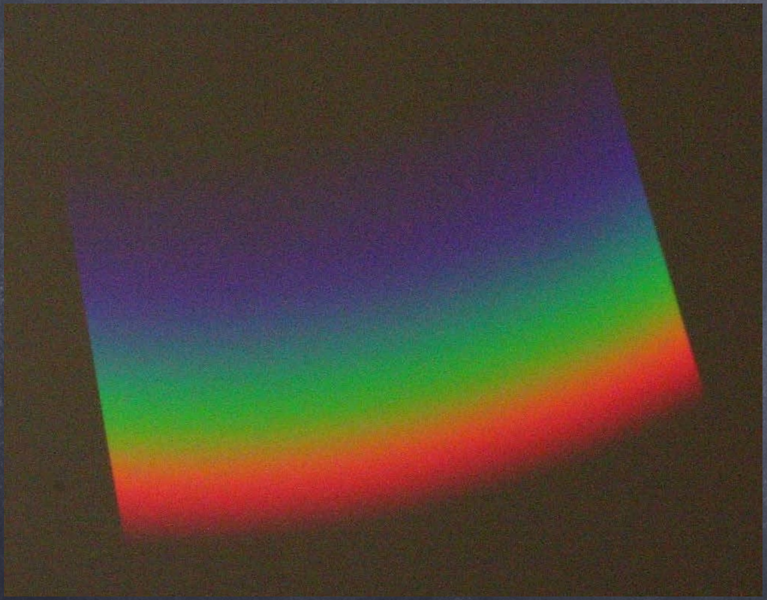
n depends on the wavelength of light.



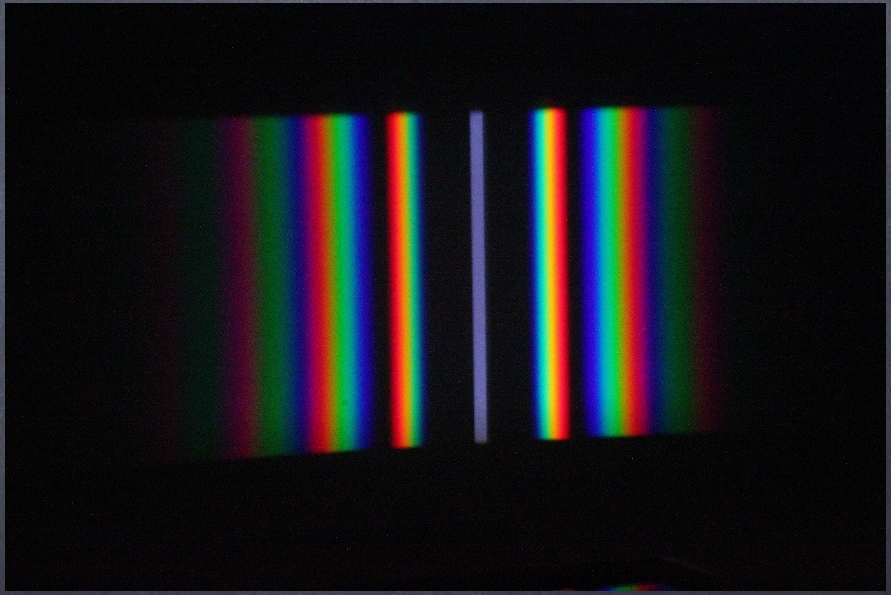
low wavelength light refracts more

Experiments done where we split light into its wavelengths

with a prism

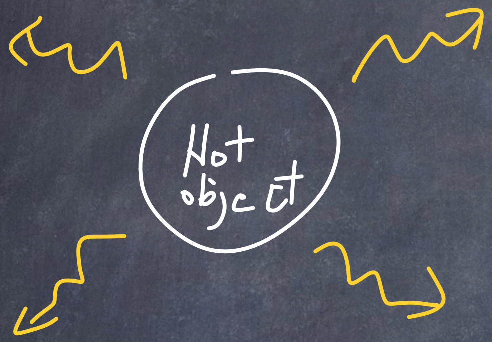


with a diffraction grating



In PHY 117, you learned that heat can be transferred by conduction, convection, & radiation (today)

Hot objects radiate EM radiation.



$$P = e\sigma A T^4$$

P: power [watts = W]

e: emissivity

σ: Stefan's Constant

$\sigma = 5.6703 \text{E}{-8} \ \frac{W}{m^2}$

T: temperature of object in K

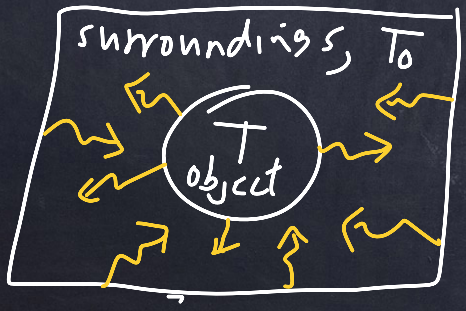
e: 0: highly reflective

1: highly absorbant

material	e
gold	0.03
water	0.95
white paint	0.88–0.92
black paint	0.9–0.98

(emissivity also depends on shininess of material)

Object will emit radiation and absorb radiation from its surroundings.



$$P = e\sigma A\left(\underset{\text{emitted}}{T^4} - \underset{\text{absorbed}}{T_0^{\,4}}\right)$$

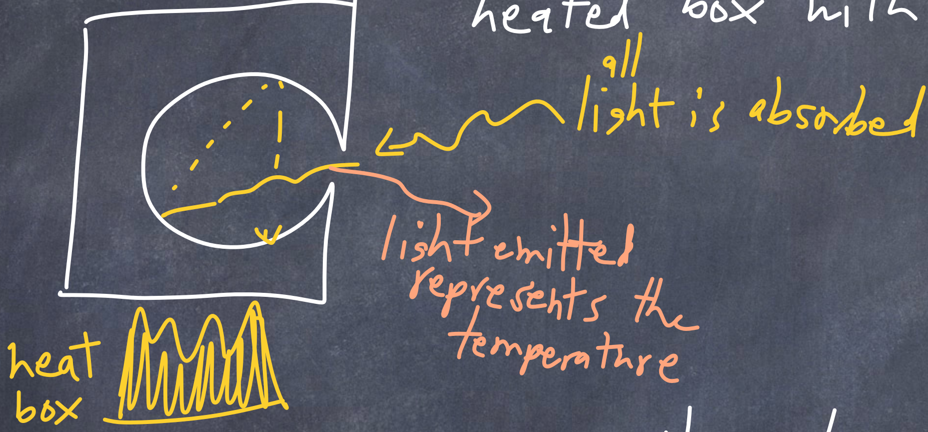
If $T > T_0$, then object will cool down with power P

If $T_0 > T$, then object will warm up with P

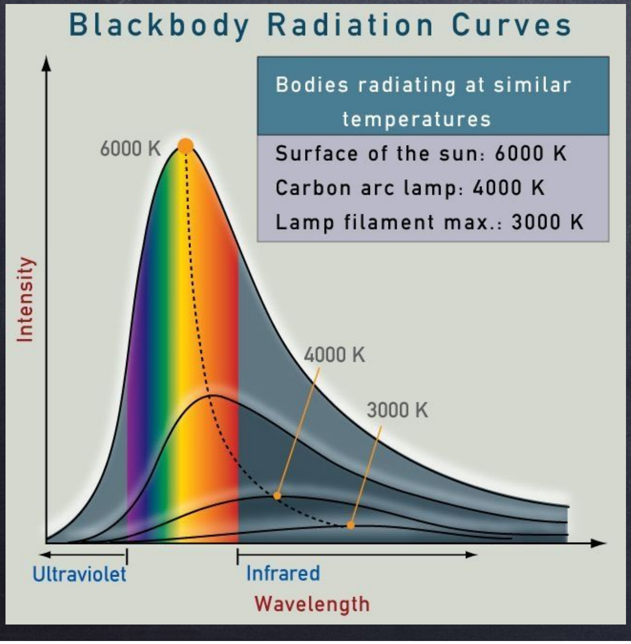
If $e = 1$, object is called a perfect blackbody. It absorbs all radiation that it receives, it also radiates perfectly.

A perfect black body is imagined like this:

heated box with a hole in it.



the characteristic radiation of a black body.



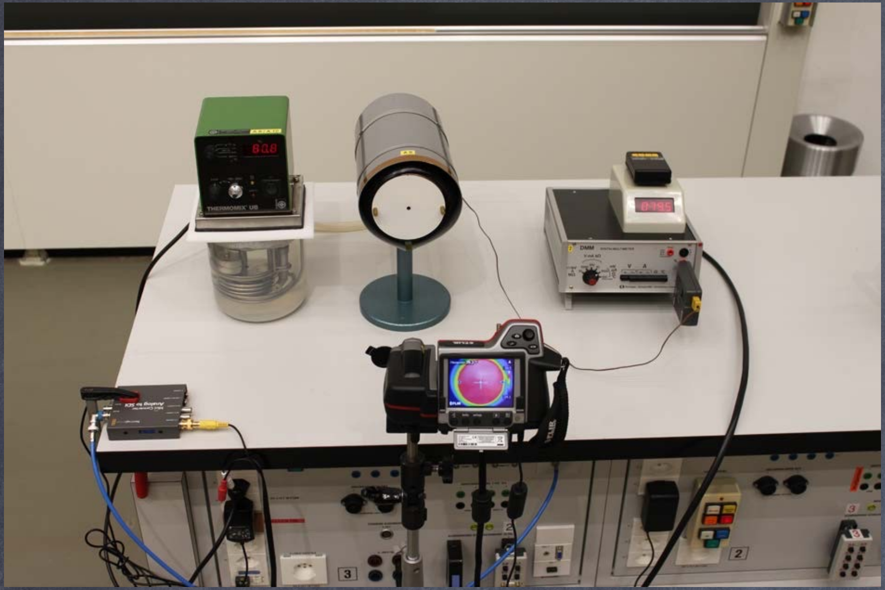
The peak wavelength depends on the temperature of the object.

$$\lambda_{max} = \frac{2.898\ \text{mm}\cdot\text{K}}{T}$$

T: temperature in K

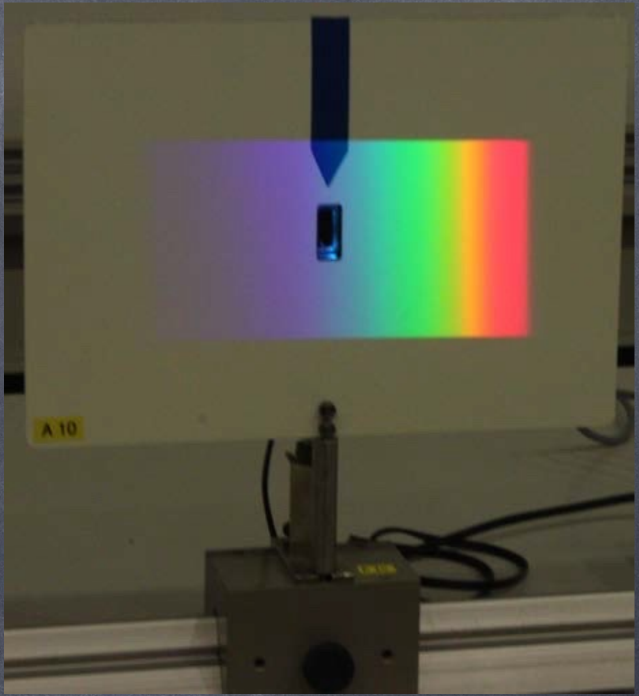
Hotter temperatures emit lower wavelength light.

Experiments where we view blackbody radiation

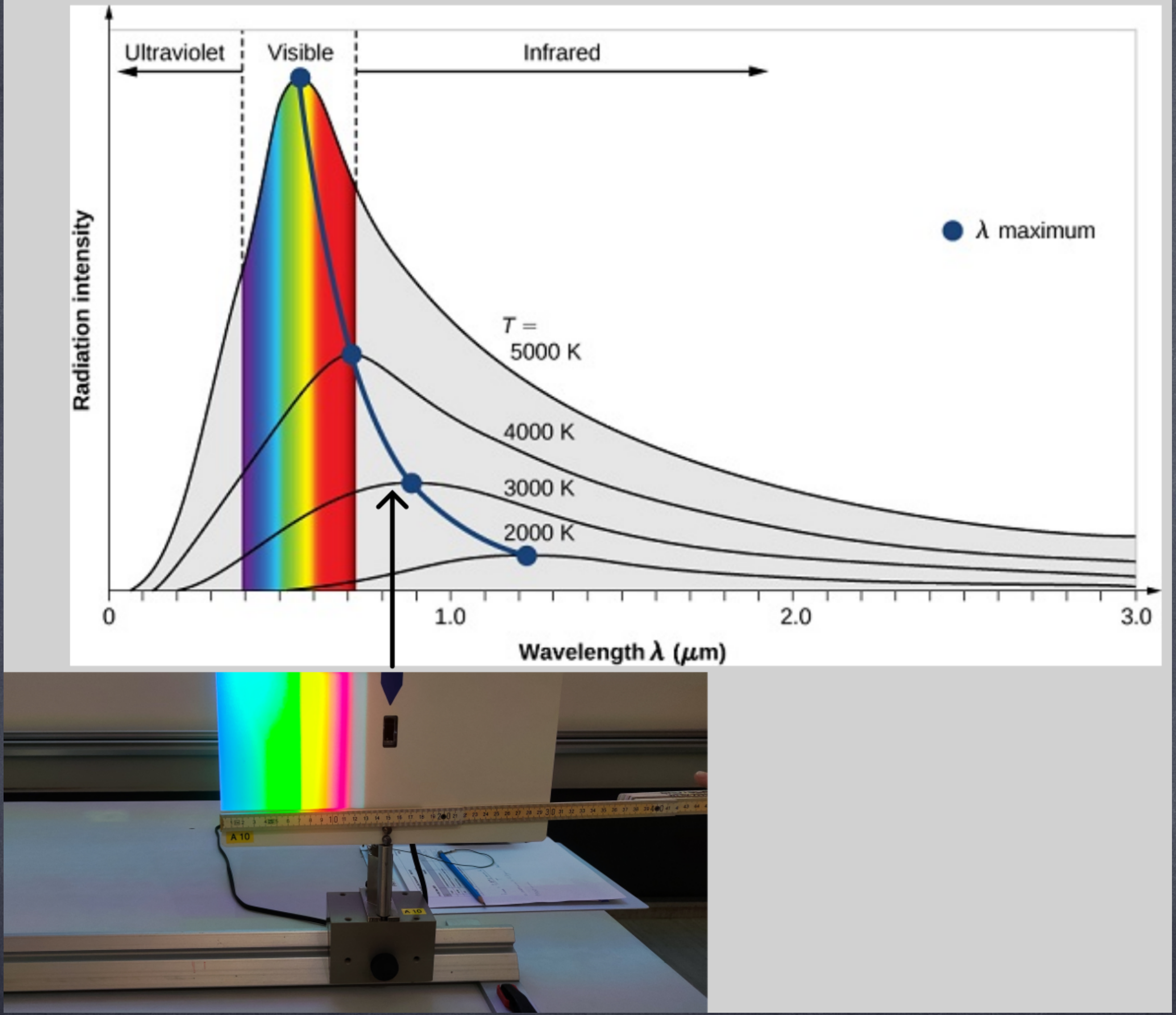


Here we see the temperature of a heated canister emitting radiation. Wien's Law lets us convert from λ_{max} to temperature assuming the value of emissivity.

Note: if we point at a material with low emissivity, the camera will mistakenly think the object is cooler than it is.



Here we measure the intensity of light emitted from a carbon arc lamp. We split the light in a prism so we can measure intensity vs. λ.



$$\frac{1000\,\mu m}{1\,nm}$$

measured:

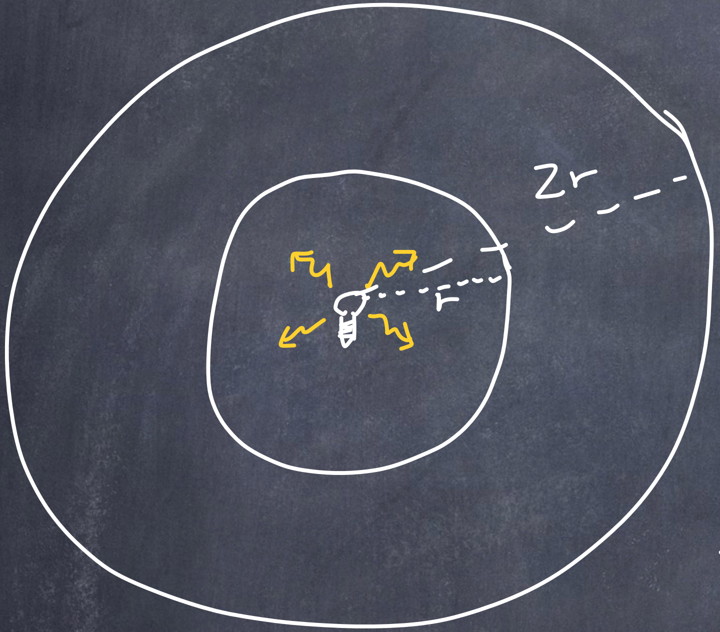
$$\lambda_{max} = 0.83\,\mu m \longrightarrow T = \frac{2.898\,mm\cdot K}{\lambda_{max}} = 3500\,K$$

This is actually correct according to manufacturer

Light intensity changes with distance.

$$I = \frac{\text{Power}}{\text{area}}$$

Sphere has a surface area of $4\pi r^2$



If light has an intensity of 100 W/m² at a distance r, what is the intensity at 2r?

$$I_r = \frac{\text{power}}{\text{area}} = 100\,\frac{W}{m^2}$$

The total power $= (I_r)(\text{area}) = \underset{\substack{\uparrow \\ 100\,\frac{W}{m^2}}}{I_r}\,(4\pi r^2)$

At 2r, $I = \frac{\text{power}}{\text{area}} = \frac{\left(100\,\frac{W}{m^2}\right)\left(\cancel{4\pi}\cancel{r^2}\right)}{\cancel{4\pi}\,(2\cancel{r})^2} = \frac{100\,\frac{W}{m^2}}{4}$

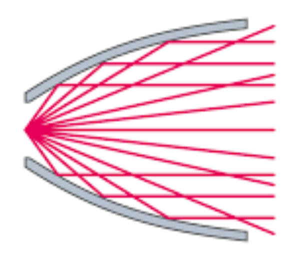
$$I = 25\,\frac{W}{m^2}$$

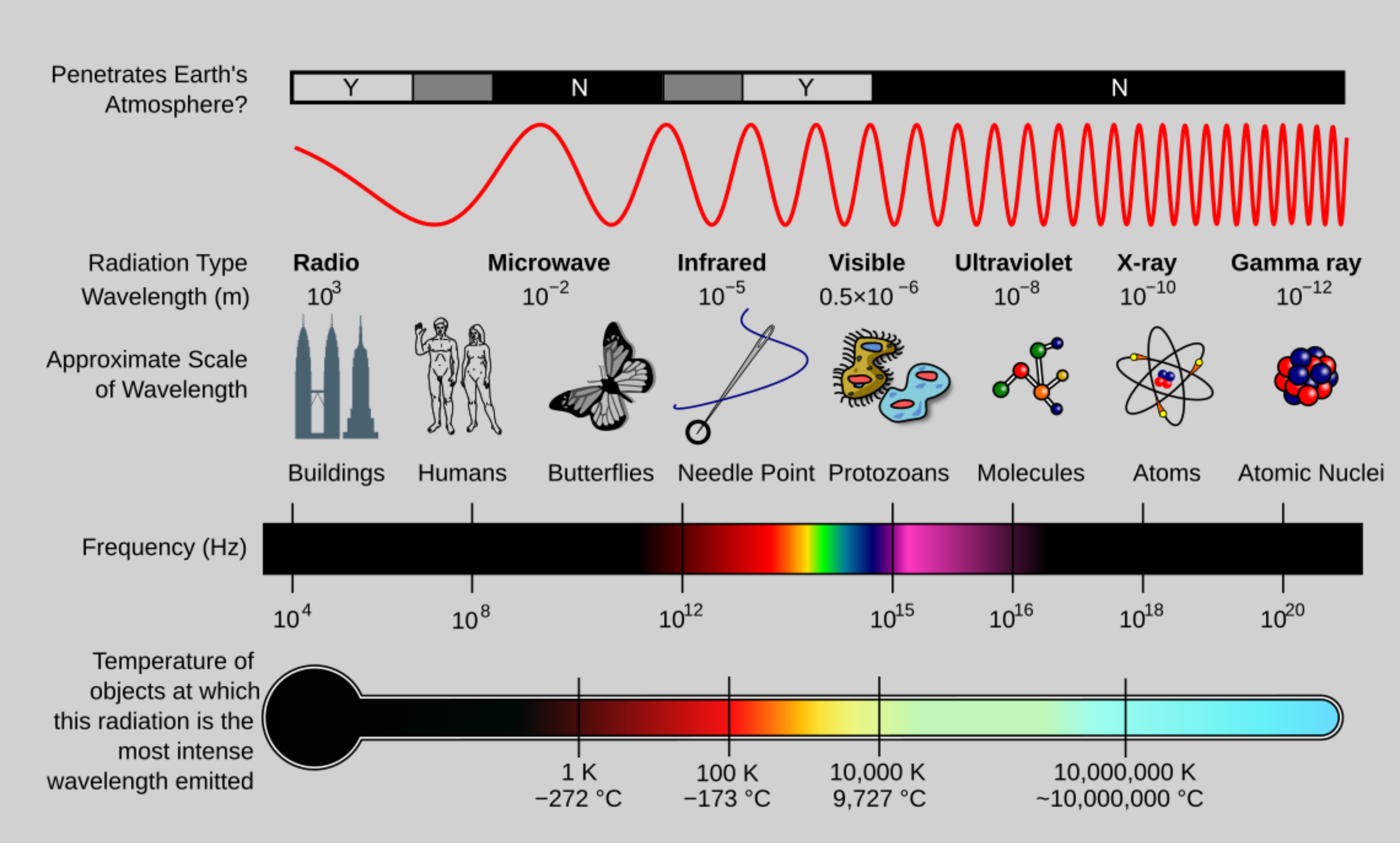
Note: efficiency of a light bulb:

incandescent: 10-20%
LED : 40-50%

} This is the efficiency to convert electrical energy to light energy so (power of light) = (efficiency) * (power of electricity)

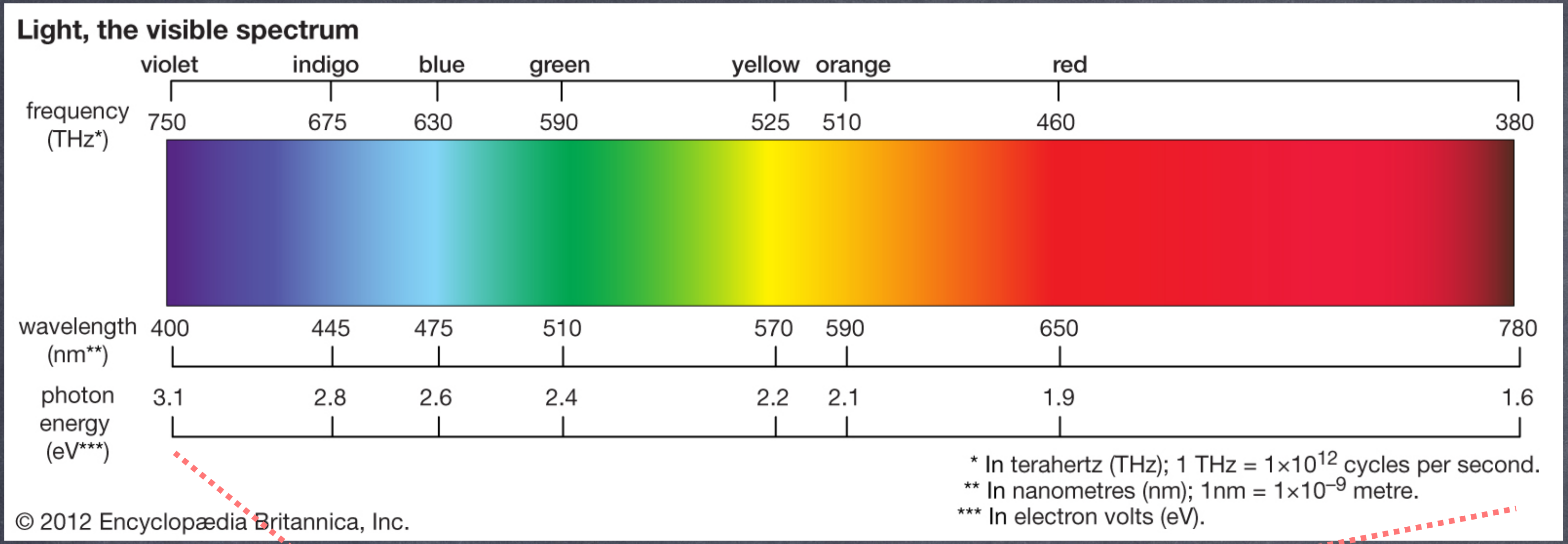
Also note that some light bulbs don't emit spherically since it is focused in one direction:





T of outer space is 2.7 K → microwave radiation

we observe the "cosmic microwave backround"
temperature using microwave antennas



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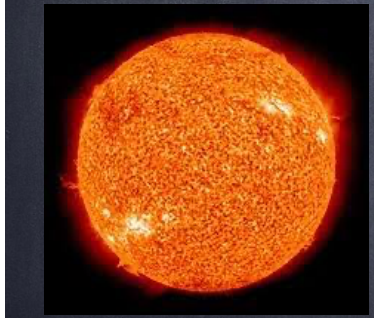
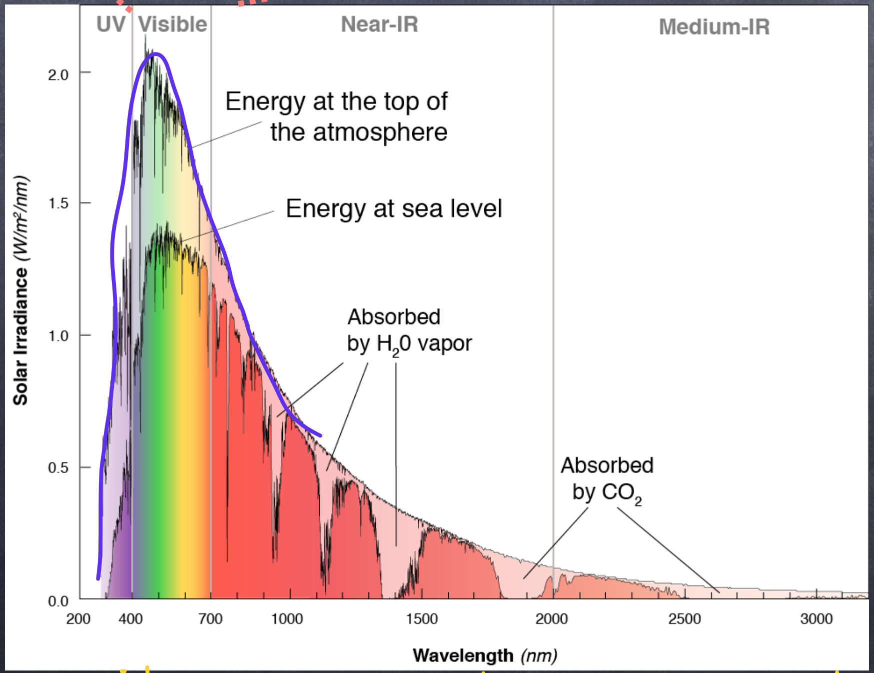
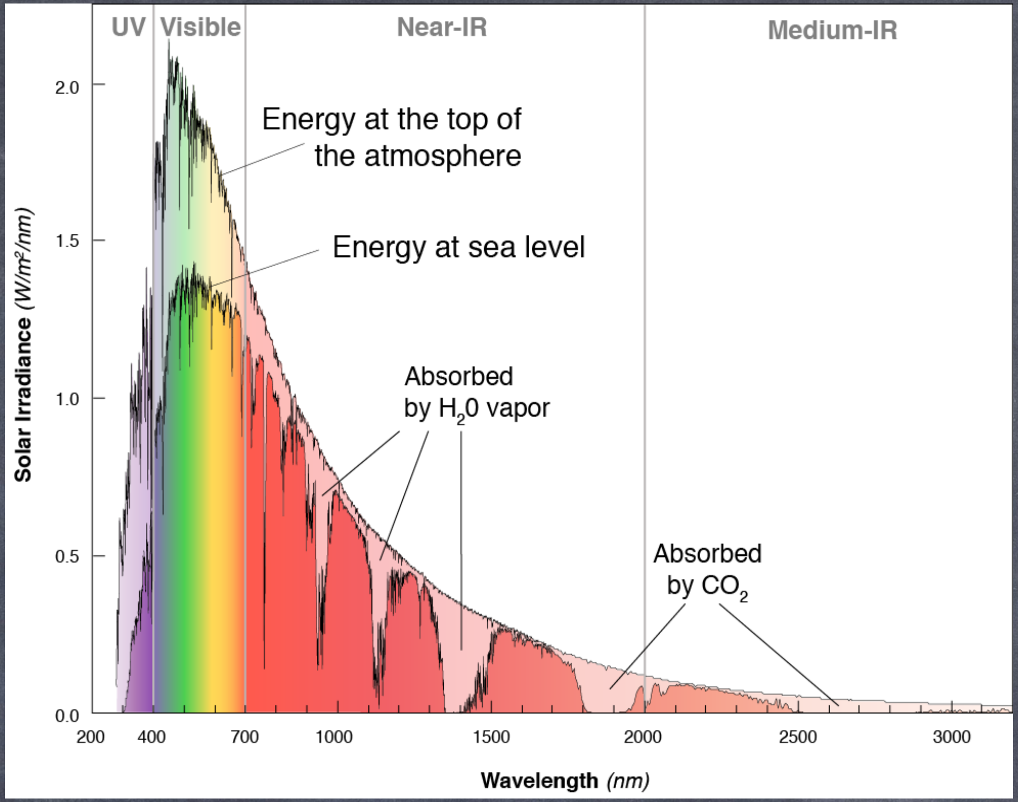


The sun radiates as a perfect blackbody



intensity vs. wavelength of sunlight

λ_{max} for the sun ~ 500 nm

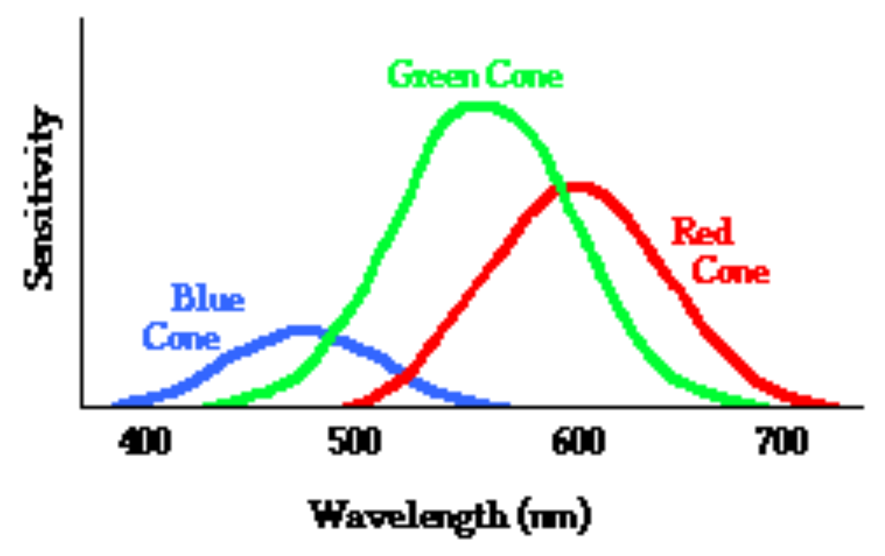


Human retina contains rods + cones.

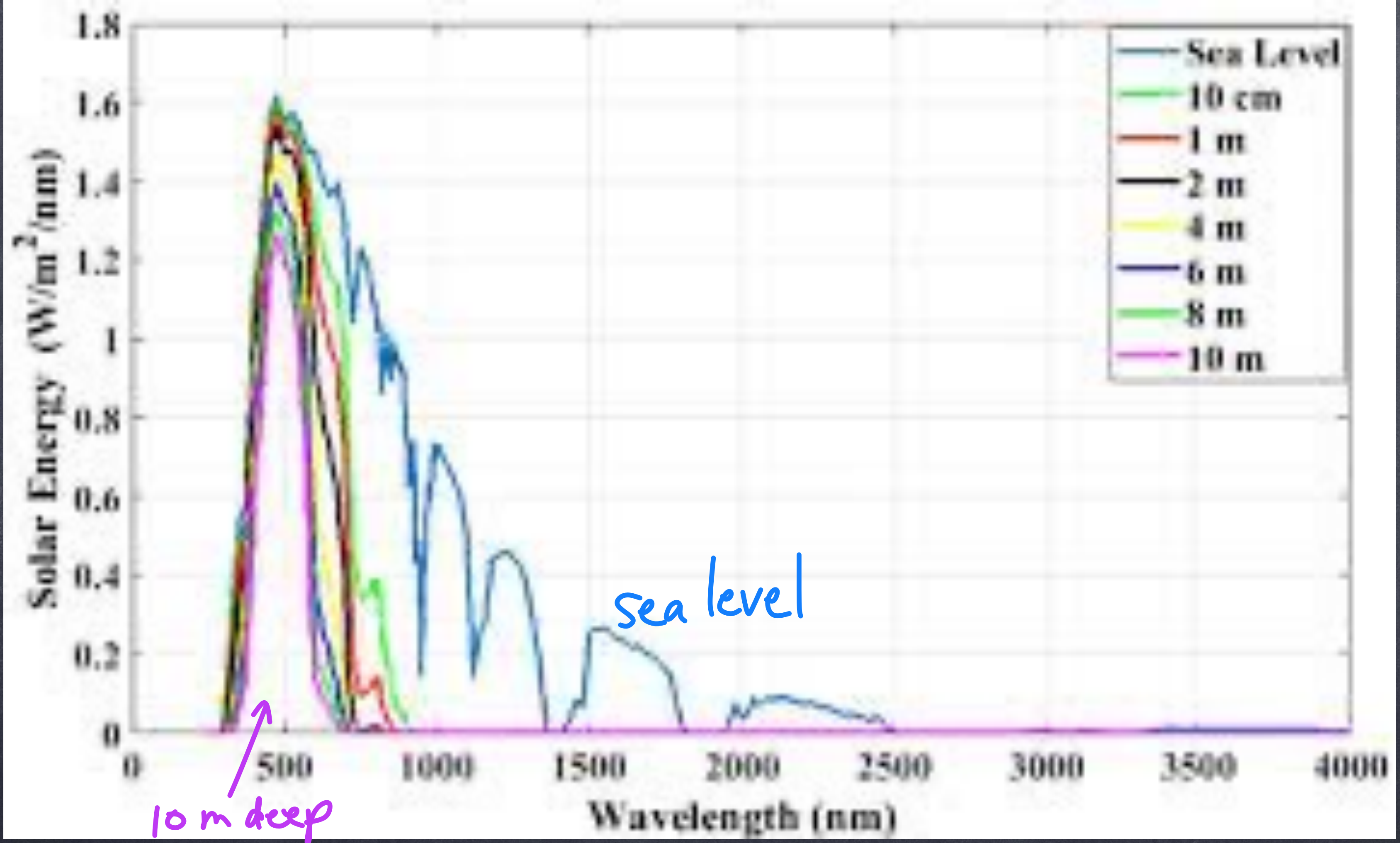
→ Rods measure the intensity of light.

→ cones measure light color.

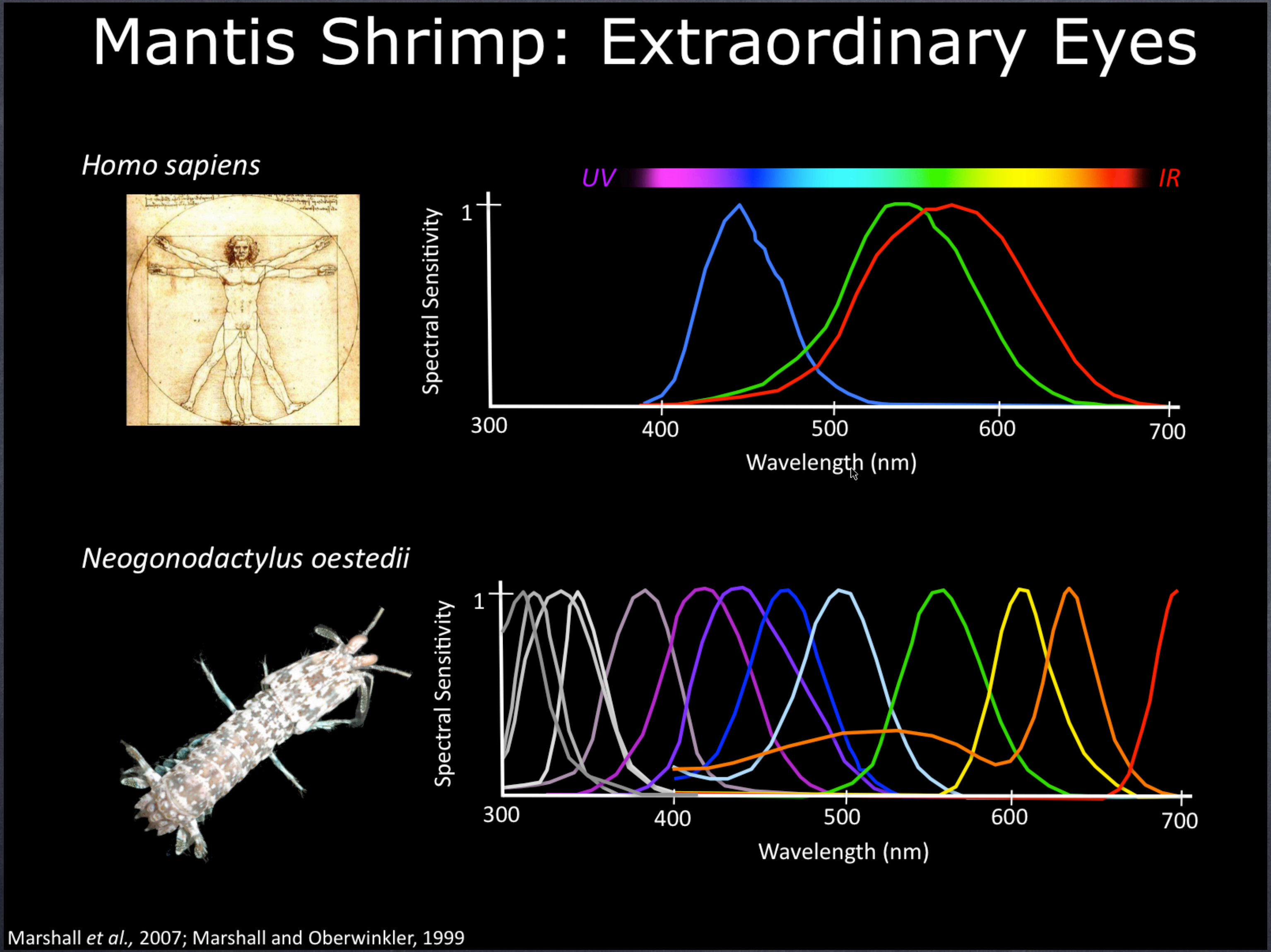
Human eye has 3 cones; sensitive to different λ of light.



Intensity of sunlight below sea level.



higher wavelength light is reflected or absorbed.



Mantis Shrimp: Extraordinary Eyes

Homo sapiens

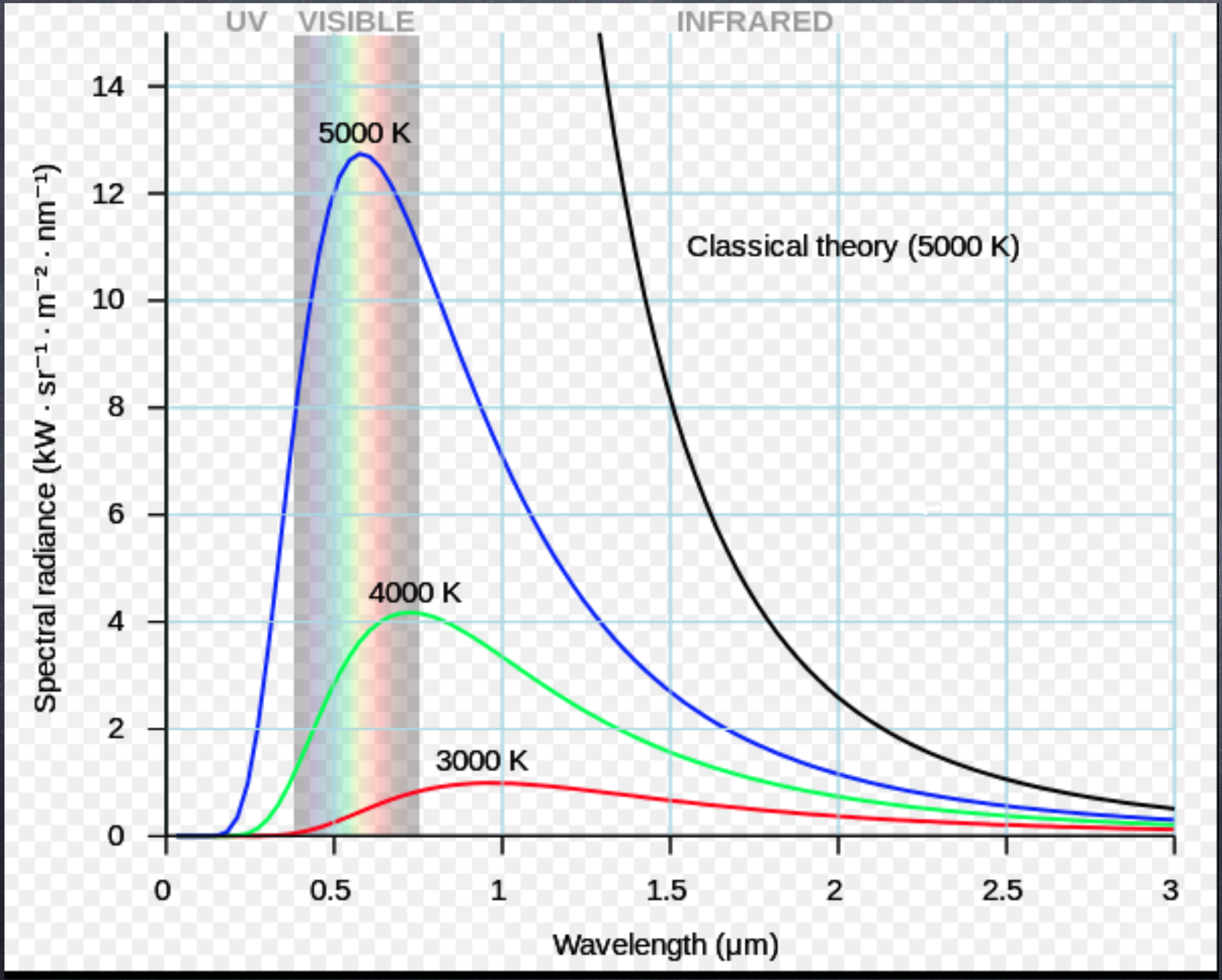
Neogonodactylus oestedii

Marshall *et al.*, 2007; Marshall and Oberwinkler, 1999

↑

extra sensitivity to low wavelengths

The mystery of blackbody radiation. (19th century)



classical theory predicts an infinite amount of low wavelength light from blackbody radiation.

(Not what is observed.)

This was solved by Planck.

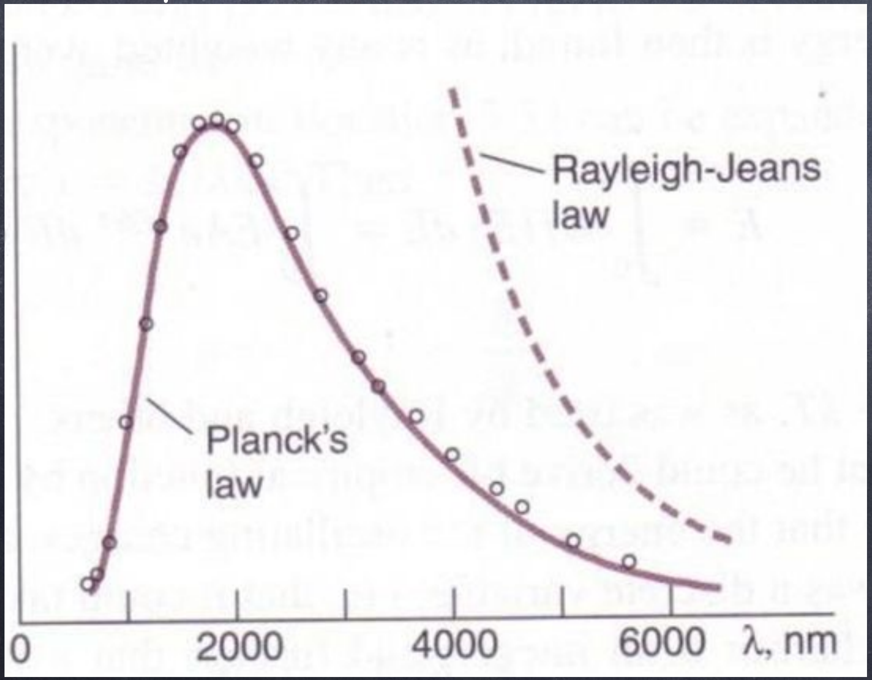
$$\text{Intensity} = I = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

k: Boltzmann constant $k = 1.38E{-23}\ J/K$

same as (PV = nkT)

h: Planck constant = $h = 6.261\ E{-34}\ J.s$

planck's



← classical theory

solution of Planck:
Considers that a blackbody radiates light as if radiation was produced by little harmonic oscillators,
Each one with energy $E = \frac{hc}{\lambda}$

This worked, but no one understood why.